Reduction of Formaldehyde Emission from Phenol Formaldehyde Treated Oil Palm Wood through Improvement of Resin Curing State

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Abstract

Oil palm wood (OPW) has several imperfections, and impregnation with low molecular-weight phenol formaldehyde resin through a modified compreg method can practically enhance these properties. The treated OPW, however, releases a considerable amount of free formaldehyde and thus is unhealthy for the human being. To make it applicable for indoor material, formaldehyde emission (FE) should be lowered to 0.1 ppm or lower. The FE level of the treated OPW was reduced from 0.3 to 0.1 ppm or lower by improving the resin curing state through two approaches, i.e. modifying the hot pressing compression schedule during the process and adopting an extended drying after the process. It is acknowledged that the extended drying gave more effect on the FE reduction than that of modifying hot-pressing schedule. The combination pressing schedule of 12.5%→25%→50% and extended drying of 48 h emits the lowest, safe formaldehyde of 0.08-0.10 ppm, which is considered safe according to American National Standard Institute (ANSI) standard. The improving resin curing state through modifying the hot pressing schedule and adopting extended drying could be used as a practical way to reduce the FE level of the treated OPW to a safe level suitable for various furniture and indoor applications.

Key words: extended drying, formaldehyde emission, modified compreg method, oil palm wood, phenol formaldehyde

Introduction

The growth of world population along with steady economical development in developing countries for the last few decades has significantly increased the demand on wood for furniture and housing materials. On the other hand, the supplies of wood have decreased uninterruptedly that lead to a serious deficit of material for the wood industry sector. Under such a circumstance, there is no choice but to use lesser used species and other lignocellulosic materials from agricultural wastes as alternative raw materials. In the major oil palm countries, such as Malaysia and Indonesia, oil palm trunk residues from clearing matured trees for replanting are the most promising alternative material. According to Bakar *et al.* (2005a), the wood from the outer part of oil palm trunk (henceforth oil palm wood, OPW) can be used as solid wood upon properly treated. Without treatment, OPW has at least four imperfections: low strength, low dimensional stability, low durability, and poor machining characteristics.

Impregnation of OPW with low-molecular weight PF resin (Lmw-PF) through a modified compreg method can practically solve all imperfections of OPW. This treatment significantly improve its properties, yielded good appearance thus can be used for high-grade furniture and housing materials (Bakar *et al.* 2005b, 2007a).

Nevertheless, the treatment of OPW with Lmw-PF leads to another problem. The drawback of this treatment is the emission of considerable amount of free formaldehyde from the resin from the products (Amarullah *et al.* 2009). It is inherent characteristic of Lmw-PF, in which it has more formaldehyde emission (FE) and, to make it worse, there is no zero or even less emission Lmw-PF commercially available.

Having a high FE level, the treated OPW is neither safe to be used nor environmental friendly material. The free formaldehyde is carcinogenic chemical substances which are appreciable cancer causing potential. At high emission level, it can breakdown the human body, particularly blood and liver. Regulations that limit FE are strictly implemented in many countries, in which any wood products should comply relevant standard depend on their applications. The American National Standard Institute (ANSI), for instance, recommends an ambience limit of FE of 0.1 ppm as a safe level for indoor applications materials (Nuess & Price 2007).

Based on its physico-mechanical properties and appearance, the treated OPW is very suitable for furniture and other indoor applications (Bakar *et al.* 2007a, 2007b). For being so applicable, the FE level of the treated OPW must be lowered to a safe level as prescribed in relevant standards. Improvement of resin curing state has been known as a way to reduce the FE of the treated wood (Roffael 1993). However, the information about FE and the study about the FE reduction of treated OPW are very limited. The objective of this study is to determine the FE level of the treated OPW and evaluate the effectiveness of curing stated improvement of resin used against the FE reduction.

Materials and Methods

Materials and sample preparation

A total of 6 matured oil palm trees (28-year old) from Taman Pertanian Universiti-UPM, Serdang, Malaysia were selected for raw material. Only the bottom parts of 4 m length trunks were used, in which the trunks were sawn into 5 cm thick OPW lumbers with a polygon sawing method (Bakar *et al.* 2006). The Polygon sawing was employed in order to have the best, homogeneous, tangential outer OPW lumbers. Due to un-homogenous characteristic of material in term of density (Lim & Koo, 1986), only selected outer OPW lumbers having relatively same density (410-510 kg m^{-3}) were used in this study. The lumbers were then dried in a kiln to 15% moisture content. After drying the OPW was cut into test sizes, and labeled before proceeding to the following treatment process. A total of 96 pieces of 100 mm wide, 100 mm long and 40 mm thick samples were prepared.

A modified compreg method consisted of four steps viz. drying, impregnation, resin semi-cured heating, and hot-pressing densification was adopted in the treatment (Bakar *et al.* 2005a, 2007b). The samples were impregnated with Lmw-PF (15 solid content) in an impregnation cylinder at a pressure of 120 psi for 30 min. The impregnated samples were then heated in an industrial microwave oven for 12 min to allow partially cured of resin and bulked the OPW structure. Finally, the samples were subjected to hot-pressing densification to a pre-determined thickness of 2 cm (compression level of 50%) at a temperature of 150 ± 5°C for 45 min.

Formaldehyde reduction treatments

In order to reduce FE level from the treated OPWs, the above treatment process was furthermore modified. The aim was to improve the curing state of the resin. The schedules of hot-pressing compression were varied in combination with various extended drying periods. With a total compression of 50% (from 4.0 mm to 2.0 mm thick), the compressions of hot press were employed in 2 to 3 stepwise pressing schedules. The hot-pressing compression schedules were varied for 12.5%→25%→50%, 12.5%→37.5%→ 50%, and 25%→50%. The extended drying was varied from 0, 24, and 48 h in an oven at a maintained temperature of 103 ± 2°C.

Determination of FE level

Determination of FE level was done by desiccators testing method based on Malaysian Standard MS 1787, Part 15:2005 (MS 2005). Sets of test specimens of predetermined surfaces area (1800 cm^2) were placed in a desiccator of controlled temperature (20 ± 5°C) and the quantity of emitted formaldehyde absorbed in a specified volume of water during a period of 24 h was recorded. The concentration of formaldehyde in aqueous solution was calculated by the acetyl-acetone method, and the concentration of formaldehyde due to the test pieces was calculated by the following equation:

$$G = f \times (A_d - A_b) \times 1{,}800/S$$

Where:

G : the concentration of formaldehyde due to the test pieces, in ppm or mg l^{-1};

A_d : the absorbance of the solution from the desiccators containing the test pieces;

A_b : the absorbance of the background formaldehyde solution

f : the slope of the calibration curve for the standard formaldehyde solution, in mg $^{-1}$

S : the surface area of the test pieces, in cm^2

Results and Discussion

The FE levels of the samples were significantly reduced when the curing state of the resin was improved through altering the hot-pressing compression schedule and extending drying in an oven (Fig. 1). The FE level was reduced from average of 0.3 ppm to a threshold safe limit of 0.1 ppm when the pressing schedules of 12.5%→25%→50% and 12.5%→37.5% →50% with combination of extended drying of 48 h. Both the hot-pressing compression schedules and extended drying treatments gave a significant effect on the FE reduction of the samples, but the later gave a more effective reduction than the former. Mean values with different letters in Fig. 1 shows significant FE different among the treatments at 95% confidence level. Regardless of the extended drying period, the mean FE levels were 0.15 ppm, 0.23 ppm and 0.27 ppm for the hot pressing compression schedule of 12.5%→25% →50%, 12.5%→37.5%→50% and 25%→ 50% respectively. On the other hand, regardless of hot pressing compression schedule, the average FE levels were 0.33 ppm, 0.22 ppm and 0.10 ppm for the extended drying time of 0 h, 24 h and 48 h respectively. In general these results suggested that any hot-pressing compression schedules could be used, especially those of 12.5%→ 25%→50% and 12.5%→37.5%→50%, as long as a 48 h extended drying in an oven was employed.The relationship between extended drying periods and FE level was understandable. A FE is free formaldehyde partly release from the impregnated Lmw-PF resin of treated OPW which is not completely polymerized (Nuess & Price, 2007). Extended drying after hot pressing helped the impregnated Lmw-PF resin being cured better and thus reduced the FE level. This study confirmed the phenomenon.

On the other hand, the relationship between the hot-pressing compression schedules and FE levels could be possibly due to the following reasons. The compression during hot-pressing densification determined the amount and pressure of steam released, and those also correlated to the amount of free formaldehyde released. The higher the compression, the more the steam released, and the more the free formaldehyde released. On top of that, a steeper compression, especially at the final compression step, caused the higher release of steam and that could possibly increase the formaldehyde release. In fact, the compression schedule of 12.5%→25%→50% experienced a steeper final compression (25% to 50%), and therefore released more formaldehyde during the hot-pressing. In contrast, the compression schedule of 12.5%→37.5% →50% experienced less steep final compression (37.5% to 50%), and thus released less formaldehyde during the hot-pressing. The entrapped free formaldehyde was slowly emitted from the sample after the hot-pressing densification being completed and this makes the FE reading during the test become higher. It was why during the FE tests after one week conditioning, the FE reading from the 12.5%→37.5%→50% samples were higher than those of 12.5%→25%→50% samples. However, the effect of hot-pressing compression schedule on the FE was only significant when the extended drying was not implemented. The effect was minimized with the value range from 0.09 ppm to 0.13 ppm when the extended drying was implemented.

As shown in Fig. 2, the resulted resin loads viz. the increment of weight due to the resin penetration onto the sample varied from 10% to 20%. It had been expected that the FE level would have had a correlation with resin load. An increase in the resin quantity leads to an increase in the formaldehyde emission, but the increment does not proportionate (Roffael 1993). The resin load also plays important role in determining the final properties (Rowell 2005, Bakar *et al.* 2005a, 2007a, 2008). Nevertheless, it is interesting to note that the amount of resin load among the treatment (Fig. 1) does not conform to the amount of the FE (Fig. 2). Treatments with 24 h extended drying at 12.5%→ 37.5%→50% and 25%→50% compressing schedules had higher resin load value, but emit low amount of formaldehyde. These results suggested that the resin load of the treated OPW had no correlation with the FE level.

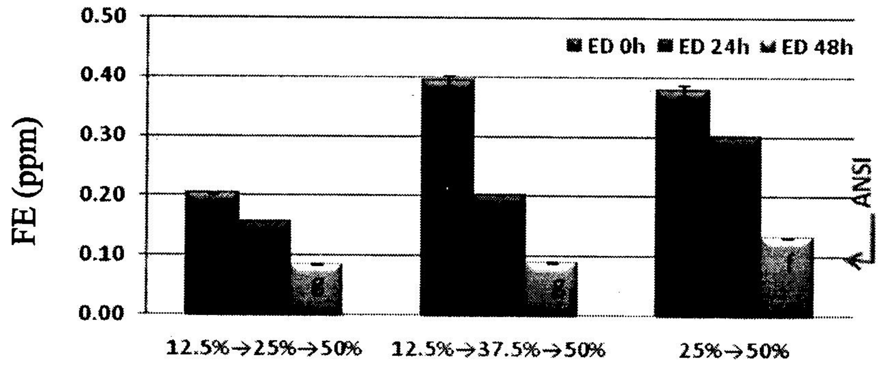

Figure 1 Mean FE values of treated OPW under various treatment conditions. Letter in each bar indicates value significance different among the treatment and ⌶ sign indicates standard deviation value within set of treatment.

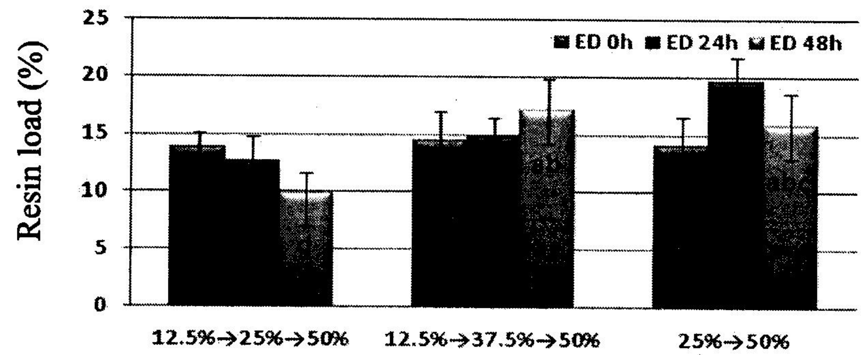

Figure 2 Mean resin loading values of treated OPW under various treatment conditions. Letter in each bar indicates value significance different among the treatment and ⌶ sign indicates standard deviation value within set of treatment.

Conclusion

It is concluded that that both hot-pressing compression schedule and the extended drying give a significant effect on the extent of formaldehyde emission of treated OPW. Combination treatments of 12.5%→37.5%→50% and 25%→50% hot-pressing compression schedule and 24 h extended drying can practically reduce the FE level of the material to a threshold safe limit determined by ANSI standard. The amount of resin load may affect the properties of the material, but it does not correlate to the FE level.

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